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Numerical Analysis of CFRP Wrapped RC Column

Safna M S[1], Sanya Mariya Gomez[1]
[1]*(M.Tech Student,Civil Department, SCMS School of Engineering & Technology/ M G University, India)*
[2]*(Assistant Professor, Civil Department, SCMS School of Engineering & Technology/ M G University, India)*

ABSTRACT *: The deterioration of concrete is a serious issue which may lead to the corrosion of the reinforcing steel and spalling of the concrete. The external confinement of concrete members by means of wrapping high-strength fiber composite around the perimeter of the member enhances their strength and ductility. The thesis mainly deals with the numerical analysis of Carbon Fiber Reinforced Polymer (CFRP) wrapped RC columns. Here CFRP wrapped RCC column is analyzed using finite element software, ANSYS. The nonlinear analysis is carried out for concentric as well as eccentric loading of the RCC column. The ultimate load capacity of both wrapped and unwrapped reinforced concrete column specimen is determined using three dimensional models. The percentage of difference in ultimate load carrying capacity of experiment and analytical model varies between 2.22% to 7.64%. The percentage of increase in efficiency of wrapped over unwrapped is found to be 14.69%. A parametric study is also conducted by varying the ply orientation of the fiber laminates. The study helps to determine the optimum ply orientation from the six set of ply orientations studied. The optimum ply orientation scheme obtained is 90/90/90/90. The work highlights the suitability of CFRP wrapping for strengthening column.*

Keywords - *Carbon Fiber Reinforced Polymer, Compression member, Concrete column, Nonlinear analysis, Ply orientation*

1 .INTRODUCTION

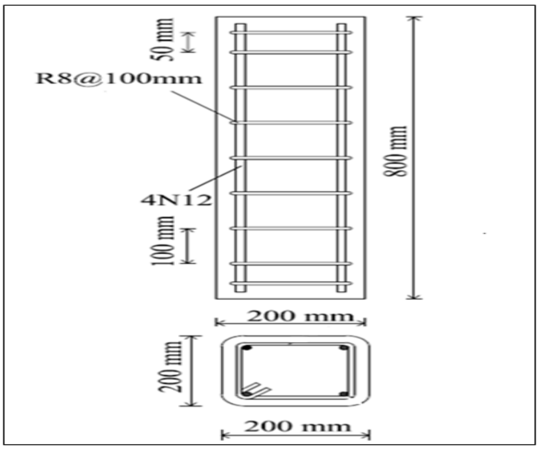
Understanding the response of the composite before and after strengthening during loading is crucial to the development of an overall and efficient and safe structure. Many methods have been utilized to study the response of structural components. Experimental based testing has been widely used as a means to analyse individual elements and the effects of concrete strength under loading. While this is a method that produces real life response, it is extremely time consuming, and the use of materials can be quite costly. The use of finite element analysis to study these components has also been used.

By understanding the use of finite element packages, more efficient and better analyses can be made to fully understand the response of individual structural components and their contribution to a structure as a whole. This thesis is a study of reinforced concrete columns with or without FRPs using finite element analysis to understand the response of reinforced concrete column due to concentric and eccentric compression loading.

Antonio (1998) [1], considers the practical application of nonlinear models in the analysis of reinforced concrete structures. The results of some analyses performed using the reinforced concrete model of the general purpose finite element code ANSYS are presented and discussed. *Anthony (2004) [2],* this paper gives a clear idea about the discrete reinforcement, the bonding of reinforcement and concrete using merge nodes and about the nonlinear static analysis. The failure of concrete is defined using Willam and Wranke model and the nonlinear response were computed using Newton-Raphson method. many researches were carried out in composite structures are *Shantakumar et.al (2004)[3], Balamuralikrishnan(2005)[4], JobThomas(2006)[5], Amer(2009)[6], Alper(2010)[7]*. The study was carried out on the unretrofitted RC beam designated as control beam and RC beams retrofitted using carbon fiber reinforced plastic (CFRP) composites with ±45° and 90° fiber orientations[3]. *Hadi (2012) [8],* Conducted a research on FRP-strengthened square or rectangular HSC columns under eccentric as well as concentric loads. Parameters investigated in this study include the magnitude of eccentricity and the number of FRP layers. Three different eccentricities 0, 25, and 50 mm were investigated. In relation to the number of FRP layers, unwrapped columns, columns wrapped with one layer, and columns wrapped with three layers of CFRP were tested. Due to the significant effect of longitudinal fiber in eccentric loading, one layer of CFRP straps was applied longitudinally in combination with two layers of CFRP wrapped circumferentially. In this thesis the numerical analysis of CFRP wrapped RC column is analysed using the software ANSYS.

2. Geometry and Material Properties

The geometry and the material properties as reported by Hadi (2012)[5] were used for this study. The control column dimensions along with the reinforcement details are shown in fig 1.



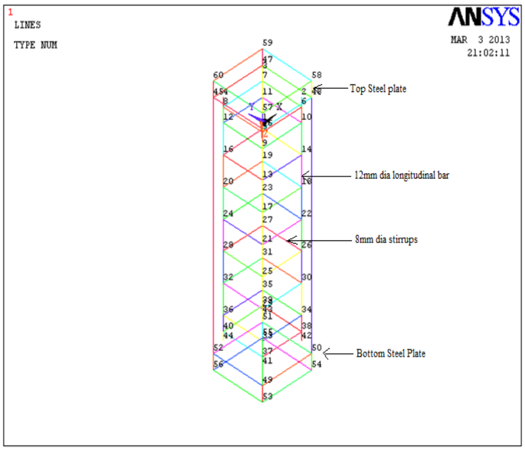


Fig 1 Details of specimen reinforcement **Fig 2** Line diagram of specimen

The average compressive strength of high strength concrete is found to be 79.5Mpa. Average tensile yield strength of 564 and 516 Mpa were obtained for N12 and R8 reinforcing bars. The carbon fiber reinforced polymer is used to strengthen the column had a nominal thickness of 0.45mm.the tensile strength, tensile strain and elastic modulus of the CFRP were found to be 1399MPa, 1.89% and 75.4GPa.the nominal thickness of the three layers of CFRP were assumed to be equal to 1.35mm.

3. NUMERICAL STUDIES

3.1 Finite elements

The finite element adopted by ANSYS were used. Solid 65 elements were used to model the concrete. The rebar capability of this model was not considered[1]. All the reinforcement were modeled using Link 8-3D spar element. Solid 45 elements were used for the steel plates at support and under the load. A layered solid element, solid 46 was used to model the CFRP composites.

3.2 Modeling of reinforced concrete column.

For this numerical studies, six column specimens were considering 3 unwrapped specimen (i.e, 0C0, 0C25, 0C50, where “0” represent unwrapped, “C” represent column and “ 0,25, 50” represent loading condition) and 3 CFRP wrapped specimen of 90/90/90 ply orientation (i.e, 3HC0, 3HC25, 3HC50,where “3H” represent 3 layers of horizontal wrapping, “C” represent column and “ 0,25, 50” represent loading condition). First we have to model a concrete control column specimen and with this we can generate the model of CFRP wrapped column.
To model a concrete column [13] , construct a skeleton or line element model of the structure. Assign the element type and material properties to the corresponding line or volume. The model is then meshed and the bonding between concrete and reinforcement is obtained by coupling.
The modelling of CFRP is carried out before the meshing of concrete. To create FRP, a volume is extruded from the four lateral faces of the column. The properties of FRP are assigned to the extruded volume. After modelling of CFRP, the concrete and reinforcement is meshed and the bonding between them is provided using coupling / c eqn, which is discussed above. After that only, the steel plates and laminates are meshed.

3.3 Loading and boundary condition

The specimens are placed at compression testing machine, both the ends of the column is bolted to the steel plate using bolts. The hinged support is provided at the bottom end of the column by restraining the degree of freedom U_X, U_Y, U_Z and ROT_Z and roller support is provided at the top end by restraining the degree of freedom U_X, U_Y and ROT_Z. The loading and boundary condition is applied after meshing the member. The Fig 3 shows the boundary condition applied to the ends of the column.

The force, P, applied at the steel plate is applied across the entire center line of the plate. The force applied at each node on the plate is one ninth of the actual force applied. The type of loading applied to the column is compression. Here in this analysis both concentric and eccentric loadings are considered. The eccentric loading is considered at a distance of 25mm and 50mm from the center.

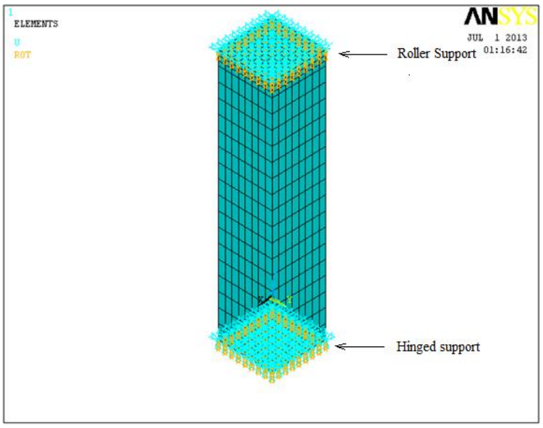


Fig 3 boundary condition for support

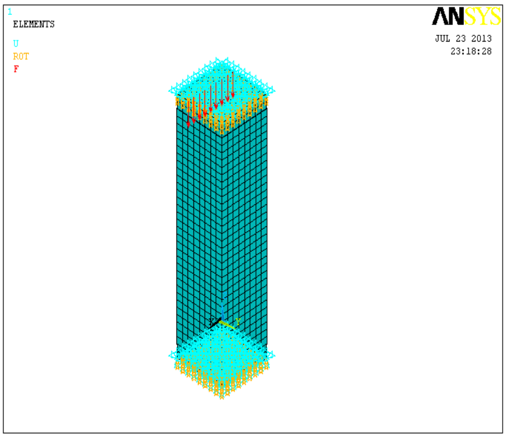


Fig 4 Loading diagram

4. ANALYSIS

Non-linear analysis is carried out for a simple column under compressive loading. For this model, the Transient analysis type is utilized[1]. The Restart command is utilized to restart an analysis after the initial run or load step has been completed. The use of the restart option will be detailed in the analysis portion of the discussion. The Sol'n Controls command dictates the use of a linear or non-linear solution for the finite element model. Here in this thesis the analysis is carried out for transient and large displacement.

4.1. Load deflection curves

The experimental and numerical load-deflection curves obtained for the column are illustrated below. The curves show good agreement in finite element analysis with experimental results throughout the entire range of behaviour and failure mode, for all beams the finite element model is stiffer than the actual column in linear range. Several factors may cause the higher stiffness in the finite element models. The bond between the concrete and steel reinforcing is assumed to be perfect in the finite element analyses, but for actual columns the assumptions would not be true slip occurs, therefore the composite action between concrete and steel reinforcing is lost in the actual columns. Also the micro cracks produced by drying shrinkage and handling are present in the concrete to some degree. These would reduce the stiffness of the actual columns, while finite element models do not include micro cracks due to factors that are not incorporated into the models.

The load- displacement graph seen below represents the unwrapped column with different eccentricities. The concentric load(Figure 5) consist only axial displacement in z direction and the eccentric load (Figure 6 and Figure 7)consist of both axial displacement in z direction and lateral displacement in y direction.

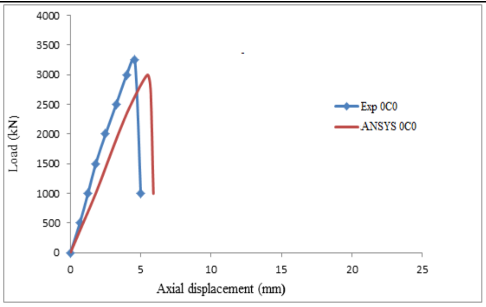
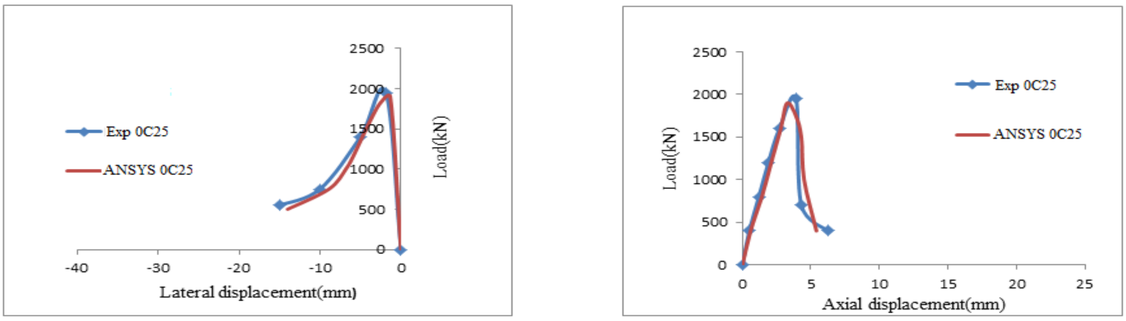
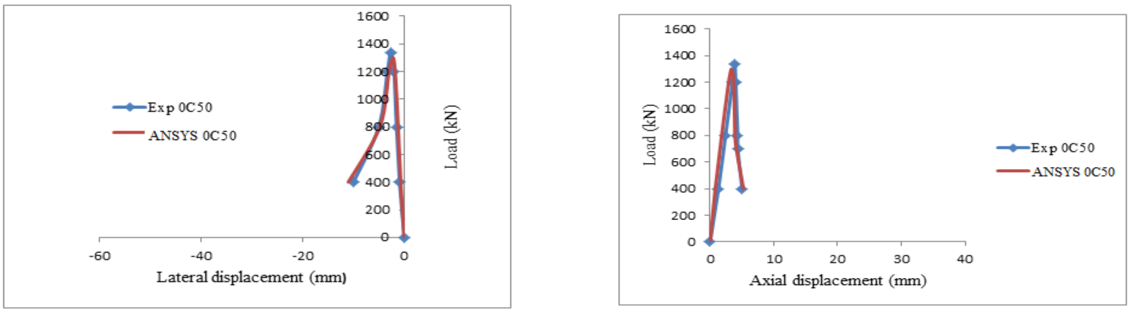


Fig 5 Load-Displacement Curves for Unwrapped Column under Concentric Loading (0C0)



(a) (b)

Fig 6 Load -Displacement Curve for Unwrapped Column Under 25mm Eccentricity:
(a) Load V/S Lateral Displacement; (b) Load V/S Axial Displacement



(a) (b)

Fig 7 Load Displacement Curve for Unwrapped Column Under 50mm Eccentricity:
(a)Load V/S Lateral Displacement; (b) Load V/S Axial Displacement.

The load- displacement graph seen below represents the CFRP unwrapped column with different eccentricities. The concentric load(Figure 8) consist only axial displacement in z direction and the eccentric load (Figure 9and Figure 10)consist of both axial displacement in z direction and lateral displacement in y direction.

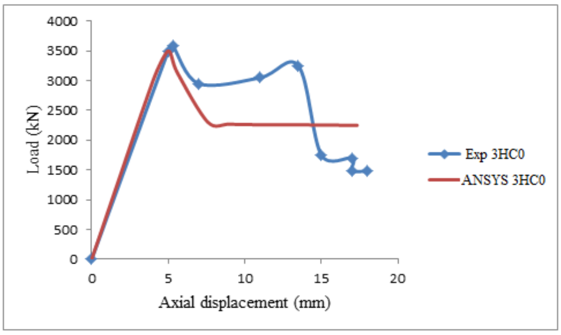
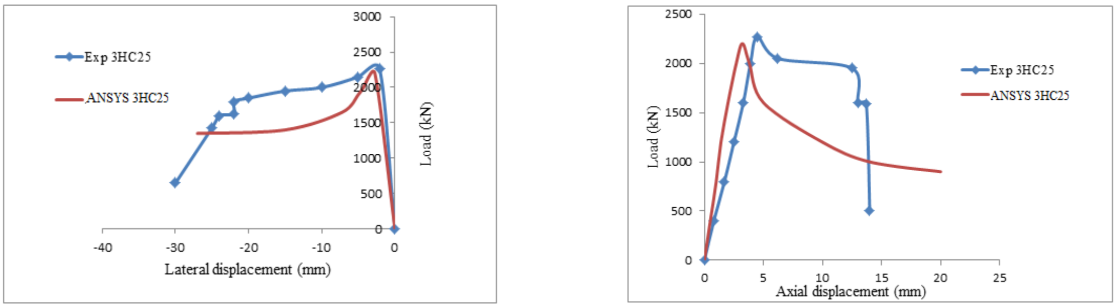
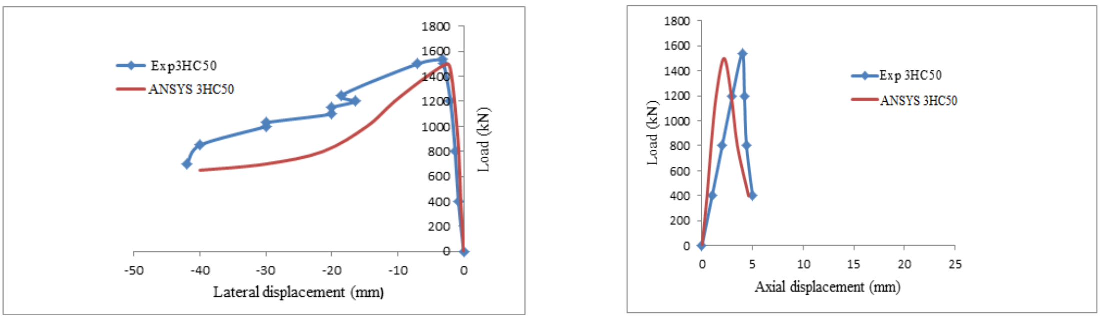


Fig 8 Load-Displacement Curves for Wrapped Column under Concentric Loading (3HC0)



(a) (b)

Fig 9 Load Displacement Curve for Wrapped Column Under 25mm Eccentricity:
(a)Load v/s lateral displacement; (b) Load v/s axial displacement



(a) (b)

Fig 10 Load Displacement Curve for Wrapped Column Under 50mm Eccentricity:
(a)Load V/S Lateral Displacement; (b) Load V/S Axial Displacement;

4.2. Failure load

The failure load obtained from the numerical solution for all columns is slightly smaller than experimental load. The final load for the finite element model are the last applied load step before the solution diverges due to cracks and large deflection. Table 1 shows comparison between the ultimate loads of the experimental columns and the final load from the finite element models.

TABLE 1 Comparison Between Experimental and Finite Element Ultimate Load.

Test column	Experiment			ANSYS			% difference of Ultimate Load
	Ultimate Load (kN)	Axial (mm)	Lateral (mm)	Ultimate Load (kN)	Axial (U_Z) (mm)	Lateral (U_Y) (mm)	
0C0	3248	4.58	-	3000	5.475	-	7.64
0C25	1950	3.91	1.87	1900	3.258	1.336	2.56
0C50	1336	3.86	2.65	1300	3.33	2.196	2.69
3HC0	3585	5.29	-	3500	4.982	-	2.37
3HC25	2269	4.48	2.11	2200	3.214	2.742	3.04
3HC50	1534	3.99	3.19	1500	2.176	2.554	2.22

4.3Efficiency Comparison

Comparing ultimate load capacities of wrapped and unwrapped column specimens obtained from the non- linear analysis. The following results were obtained

TABLE 2 Comparisons Between Ultimate Load of wrapped and unwrapped column

Eccentricity(mm)	Ultimate load (kN)		Percentage increase in ultimate load(%)
	Unwrapped column	Wrapped column	
0	3000	3500	14.29
25	1900	2200	13.64
50	1300	1500	13.33

5. PARAMETRIC STUDY ON PLY ORIENTATION

5.1 Analysis

To check the optimum ply orientation, consider the same square column of size 200x200x800mm consist reinforcement of size 12mm dia longitudinal bar and 8mm dia stirrups. The top and bottom of column consist of steel plate with a thickness of 50mm.The finite element model is then wrapped with different angle orientation of different numbers. Here some set of ply orientations were selected such as: 90 / 0 / 0 / 90, -90/ 0 / 0 / 90, 90 / 45 / 45 / 90, 90/-45/ 45 /-90, 0/ 45/ -45 /90. In which 90/90/90/90, 90/0/0/90, 90/45/45/90 were symmetric and -90/0/0/90, 90/-45/45/-90 were anti symmetric. The optimum ply orientation is carried out for concentric as well as eccentric loading.

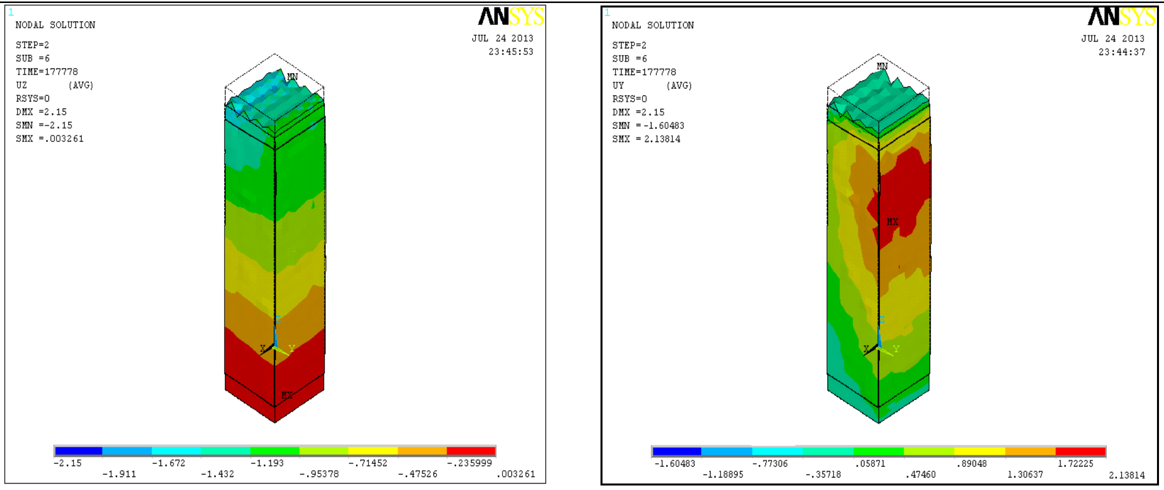
5.2 Result and discussion

The ultimate load capacity for different ply orientation is shown below in table 3. The ultimate load capacity were determined by considering different loading conditions. Fig 11 shows the displacement diagram of column.

TABLE 3 Ultimate Load Capacity of Different Ply Orientation

Ply Orientation	Ultimate Load and Displacement							
	Concentric Loading		Eccentric At 25mm			Eccentric At 50mm		
	Load (kN)	Axial (mm)	Load (kN)	Axial (mm)	Lateral (mm)	Load (kN)	Axial (mm)	Lateral (mm)
90/90/90/90	3700	4.75	2400	4.91	1.869	1600	2.15	2.138
90/0/0/90	3200	5.91	1900	4.96	2.44	1200	3.99	2.52
-90/0/0/90	3400	5.73	2200	5.54	2.68	1100	3.55	3.19
90/45/45/90	3500	4.90	2000	5.02	1.90	1300	2.56	2.24
90/-45/45/-90	3600	4.88	2200	4.95	1.89	1500	2.17	2.19
0/45/-45/90	3300	5.23	2100	4.99	2.34	1200	2.46	2.99

From the above table it is found out that the ply orientation 90/90/90/90 shows optimum compared to other ply orientations



(a) (b)

Fig 11 displacement diagram of 90/90/90/90 wrapped column at an eccentricity
(a) axial displacement (b) lateral displacement

6. CONCLUSION

The use of the finite element method to analyse wrapped and unwrapped columns was evaluated. A reinforced concrete column model was calibrated to experimental data, and the ultimate load carrying capacity and load deflection curves were compared to the experimental results. An optimum ply orientation study also carried out along with the validation.

The following conclusions were arrived based on the analytical investigation conducted on column strengthened using composites of different ply orientation subjected to compression.

1. Strengthening techniques can be adopted as a feasible solution for enhancing the compression capacity of concrete member.
2. Confinement of concrete was achieved by wrapping the specimen with the composite material. The compressive behavior of the specimens was enhanced due to the confinement pressure exerted by the strengthening material.
3. The cracking behavior of the specimen was enhanced due to the presence of CFRP the crack initiations were reduced due its high tensile capacity.
4. The concentric as well as eccentric load can be analyzed easily after inputting all the material properties.
5. The load deflection curves obtained from experiment shows a better agreement with the load deflection curve obtained from finite element analysis.
6. The ultimate load capacity so obtained from the experiment is slightly higher than the ultimate load obtained from the finite element analysis.
7. The percentage difference of ultimate load carrying capacity of experiment and ANSYS model varies between 2.22% to 7.64%.
8. From the analytical result it is found that the CFRP wrapped specimen shows a better performance i.e,
    - The control column (0C0) with concentric loading failed at an ultimate load of 3000kN. But the wrapped column (3HC0) showed an increase in the ultimate load of 3500kN. The percentage of increase being 14.29%.
    - The control column (0C25) with concentric loading failed at an ultimate load of 1900kN. But the wrapped column (3HC25) showed an increase in the ultimate load of 2200kN. The percentage of increase being 13.64%.
    - The control column (0C50) with concentric loading failed at an ultimate load of 1300kN. But the wrapped column (3HC50) showed an increase in the ultimate load of 1500kN. The percentage of increase being 13.33%.
9. 90/90/90/90 ply orientation has the better ultimate load carrying capacity compared to the other ply orientations considered.
10. Increasing the number of CFRP layers, the load and the performance of the columns can be increased

7. ACKNOWLEDGEMENT

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